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The predicted form of clusters using inter-person distance and angle: Evidence from a mock-up set at the Daegu subway station

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Abstract

This study collected a human behavior data-set regarding passengers' travel times and inter-personal distance between them on the corridor and stair. The experimental venue was a mock-up set of the Jungang-ro subway station, which is located at the Daegu Safety Theme Park. Two experiments, the first one without smoke generation, and the other not, were performed and repeated four times. We then conducted analysis based in walking speed, density, travel time and inter-personal distance and angle distribution. As a result, we predict the form of the cluster according to the inter-person distance and angle distribution

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Keywords: inter-person distance; inter-person angle; evacuation; smoke; subway

1. Motivation

Studies designed to collect human behavioural data have a long history (see Table 1). The relationship between density and walking speed has been previously developed in accordance with observations and experiments undertaken relative to different crowd situations. Studies have been performed at various places; for example, in public buildings (Predtechenskii and Milinskii (1978)) and along walkways (Fruin (1987), Hankin and Wright, (1958), Henderson (1977), Older (1968), Polus et al. (1983)), railway stations (Ando et al. (1988)), stairs

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(Predtechenskii and Milinskii (1978), Fruin (1987), Nelson and MacLennan (1995), Pauls (1995)), and queues (Fruin (1987)).

Table 1. Summary of the density and speed values reported in previous studies (Kady (2012)).

Study	Density(Persons/m2)	Crowd movement	Speed (m/s)
Ando et al.(1988)	0.8	Free	1.4-1.6
	1.8	Non-contact	0.5-1.0
	4	Restricted stagnation)	<0.5
Fruin(1987)	0.4	Adjustable	1.3-1.4
Nelson and MacLennan(1995)	0.54	Comfortable	1.2
	3.8	Slow	≈0
Older(1968)	4	Restricted	0.3
Pauls(1995)	0.54	Independent	1.25
	4-5	Restricted (standstill)	≈0
Polus et al.(1983)	0.1	Free	1.3
	2.2	Jammed	0.7

In addition, the study of walking speeds, according to the extinction coefficients in smoke conditions were performed by Jin and Yamada (1985). These studies focused on speed, density and flow. Additionally, studies of inter-personal distance were analysed relative to the left and right distance and front and rear distance of cluster forms, without considering inter-person distance or the inter-person angle of each person. Thus, we propose a method for estimating the cluster by analysing the inter-person distance and the angle of each person.

2. Method of experiment

2.1. Experimental setup

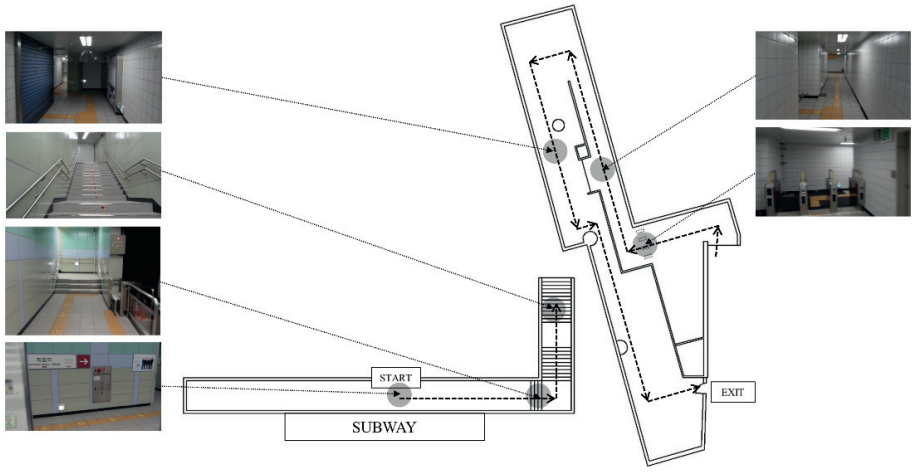

Fig. 1. Mock-up set of Jungang-ro subway station.

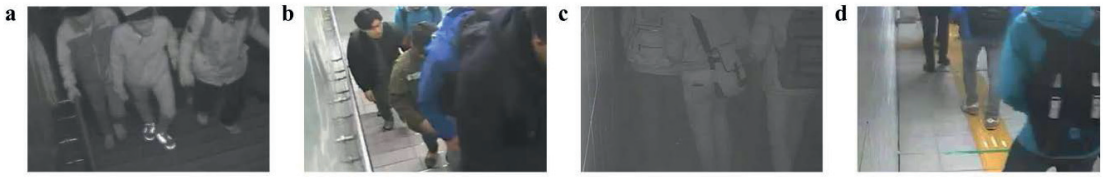

Fig. 2. Snapshots of evacuation experiment. (a) smoke-filled condition (stair) (b) normal condition (stair) (c) smoke-filled condition (corridor) (d) normal condition (corridor).

The experimental venue is a mock-up set, mimicking the Jungang-ro subway station (see Fig. 1), located in Daegu Safety Theme Park, South Korea, and used for fire and evacuation education for the general public. The venue shares identical conditions with the real station; its actual size allows visitors to experience and pass through smoke layers, and to evacuate without lighting. *80* participants were invited to participate in the experiment, and they were divided into eight groups of *10* people. The experiments were divided into two cases and each case was repeated four times. The two cases were one with smoke generation, and the other without. The participants' behaviour was recorded using a digital camera. We measured two areas (stairs and corridor) to observe and analyse human behaviour relative to differing spatial characteristics.

2.2. Methods of measurements

We measured density, walking speed, inter-person distance and angle. A description of the inter-person distance and angle measured is given in Fig. 3 below. We classify inter-person distance in two types based on *45°*. The two types are $d_{f.R}$ (distance front and rear) and $d_{l.r}$ (distance left and right). The degree of $d_{f.R}$ is less than *45°* in the area of $d_{f.R}$, and degree of $d_{l.r}$ is greater than *45°* in the area of $d_{l.r}$.

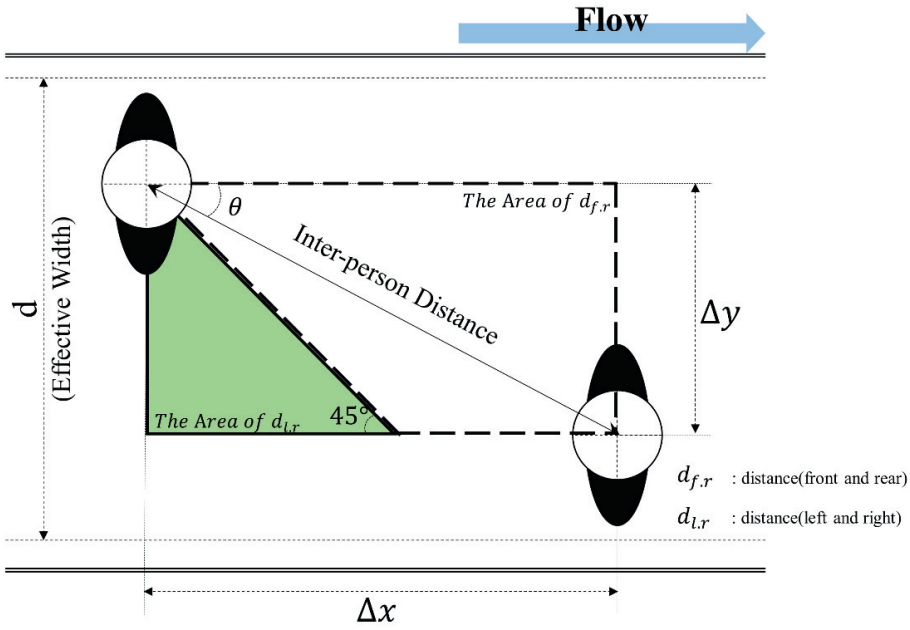

Fig. 3. Definition of inter-person distance.

Density is measured using a basic definition:

$$\rho = \frac{N}{d \cdot \Delta x}\left(\Delta x = d_{f \cdot R} \cdot \cos\theta\right) \tag{1}$$

N stands for the number of pedestrians inside a particular floor space $d \cdot \Delta x$, which is calculated by considering effective width and cluster length.

Distance S, measures the position of the person who has passed through the area during 1second. And we also measured the distance between points.

Speed V, is measured to obtain an interval Δt of *1s*. The corresponding speed V, is calculated as follows:

$$V = S / \Delta t \tag{2}$$

3. Result

3.1. Result for comparison of walking speed, travel time, density and inter-person

In Fig. 4 the resulting changes in travel time and walking speed are shown. Walking speed reduces *0.9(m/s)* to *0.76(m/s)* in smoke-filled conditions, on the corridor and *0.61(m/s)* to *0.57(m/s)* on the stair. Travel time reduces *9.75(s)* to *8.75(s)* in smoke-filled conditions on the corridor and *18.75(s)* to *18.25(s)* on the stairs. Despite walking speed decreasing, travel time reduces.

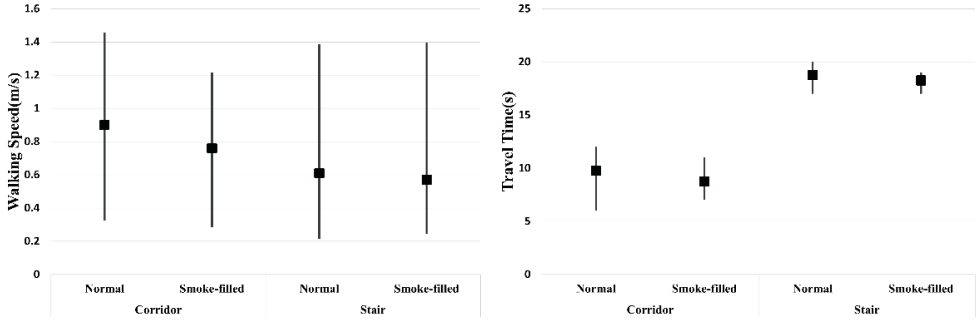

Fig. 4. Comparison (a) walking speed and (b) travel time in normal and smoke-filled conditions.

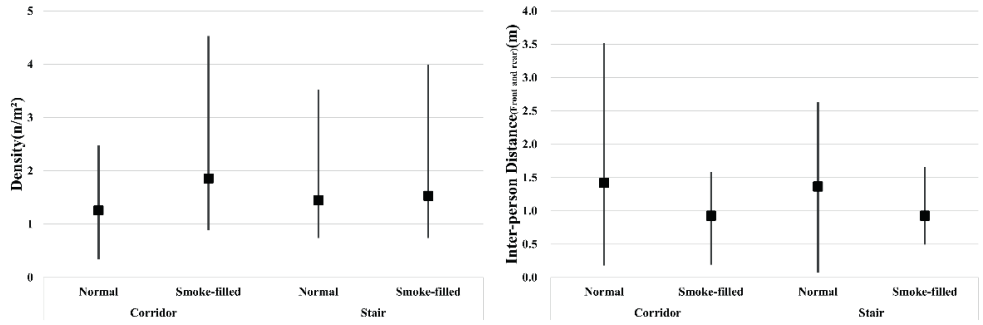

Fig. 5. Comparison (a) density and (b) inter-person distance in normal and smoke-filled conditions.

Table 2. Inter-person distance in each condition.

		Corridor						Stair					
		Smoke-filled			Normal			Smoke-filled			Normal		
		Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min
Inter -person Distance	Left and Right (m)	0.403	0.869	0.224	0.472	0.977	0.190	0.653	1.378	0.216	0.888	1.468	0.072
	Front and rear (m)	0.843	1.700	0.191	1.027	3.523	0.178	1.005	1.922	0.246	1.057	2.627	0.135

In Fig. 5 and Table 2 the resulting comparison of inter-person distance in each condition is shown. In smoke-filled conditions, both inter-person distances decrease. Comparing results in smoke-filled conditions, travel time and walking speed decrease and then density and inter-person distance increase. Therefore, the shorter travel time is caused by increased cluster length, as shown by inter-person distance. Thus, we predict the effect of the form of cluster relative to inter-person distance and angle. We also forecast the density of cluster in each condition, according to the predicted form.

3.2. Results for the distribution of inter-person distance

Fig. 6 and 7 show the resulting distribution of inter-person distance, according to each condition. In normal conditions, the average inter-person distance of front and rear and the distance between left and right are *1.057m* and 0.*888m* on the stair. In smoke-filled conditions, the average inter-person distances are *1.005m* front and rear and 0.*653m* left and right on the stair. In addition, on the corridor, the average inter-person distance is *1.027m* front and rear, and 0.*473m* left and right in normal conditions. In smoke-filled conditions, the average inter-person distance is 0.*843m* front and rear, and 0.*403m* left and right.

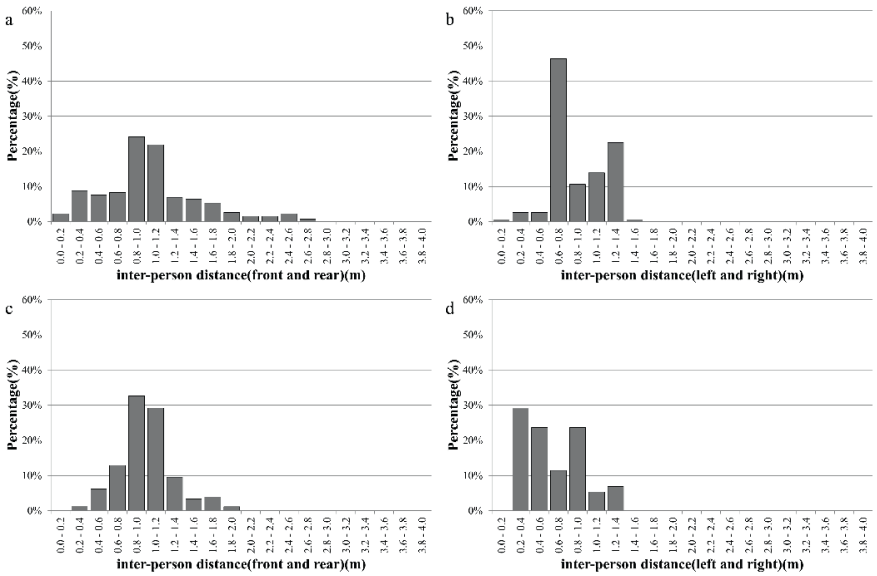

Fig. 6. The distribution of inter-person distance for each condition on stairs. (a) inter-person distance(front and rear); (b) inter-person distance(left and right) in normal condition. (c) inter-person distance(front and rear); (d) inter-person distance(left and right) in smoke-filled condition.

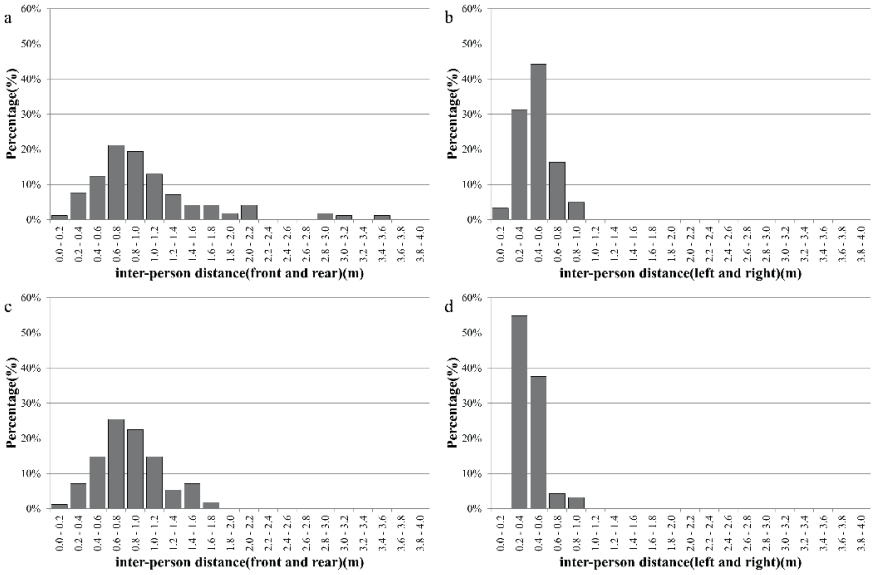

Fig. 7. The distribution of inter-person distance for each condition on the corridor. (a) inter-person distance(front and rear); (b) inter-person distance(left and right) in normal condition. (c) inter-person distance(front and rear); (d) inter-person distance(left and right) in smoke-filled condition.

3.3. The distribution of inter-person angles

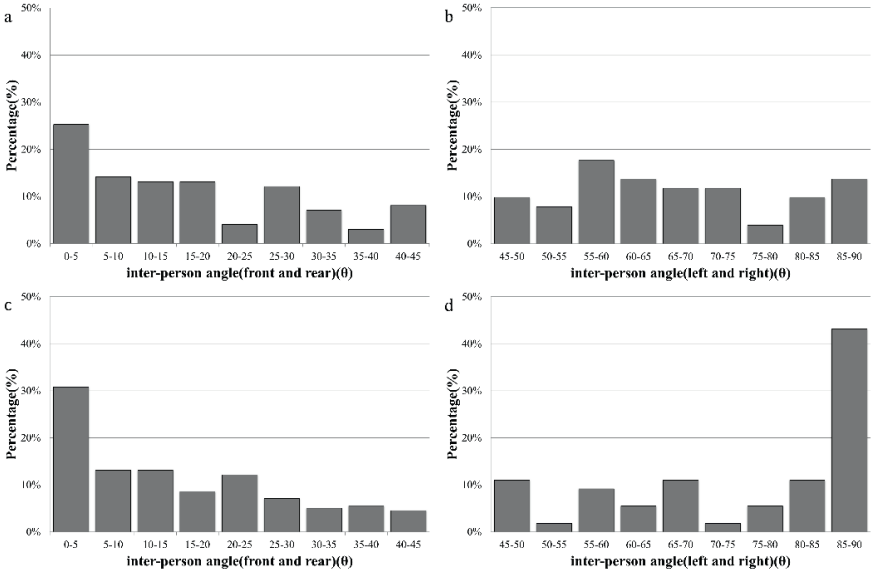

Fig. 8. The distribution of inter-person angle for each condition on the stairs. (a) inter-person angle(front and rear); (b) inter-person angle(left and right) in normal condition. (c) inter-person angle(front and rear); (d) inter-person angle(left and right) in smoke-filled condition.

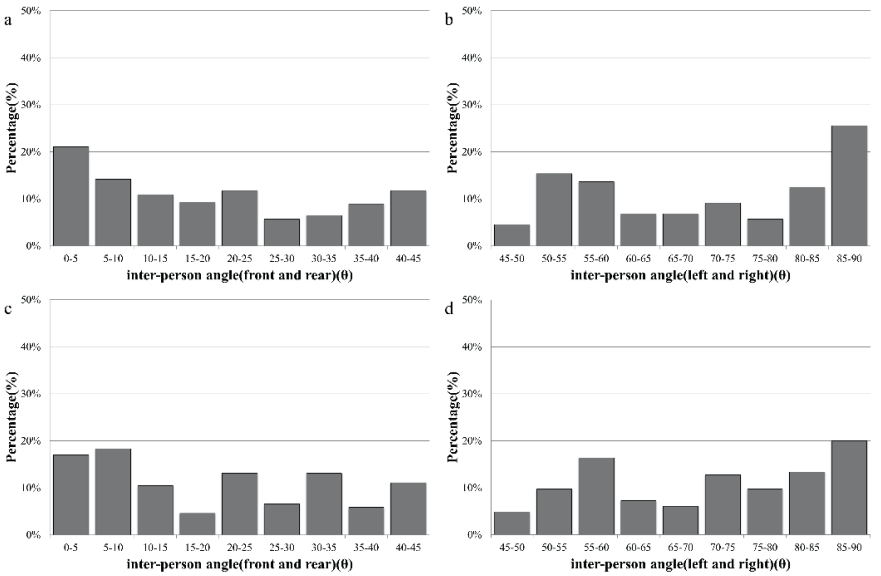

Fig. 9. The distribution of inter-person angle for each condition on the corridor. (a) inter-person angle(front and rear); (b) inter-person angle(left and right) in normal condition. (c) inter-person angle(front and rear); (d) inter-person angle(left and right) in smoke-filled condition.

In Fig. 8 and 9 the result of analysing inter-person angle distribution to predict the form of cluster is shown. In normal conditions, the average inter-person angle of front and rear, and left and right are *20°* and *71°* in the stair. In smoke-filled conditions, the average inter-person angle remains the same, *20°* at the angle of front and rear and *71°* at the angle of left and right. In addition, on the corridor, the average inter-person angle is *17°* at the angle of front and rear, and *68°* at angle of left and right in normal condition. In smoke-filled conditions, the average inter-person angle is *16°* at the angle of front and rear, and *75°* at the angle of left and right.

3.4. Inter-person distance versus Inter-person angle

In Fig. 10 shows the result of comparing inter-person distance and angle. With decreasing the inter-person angle, the inter-person distance is increasing trend. In smoke-filled condition, this trend is appeared more accurately. Also, in smoke-filled condition, both inter-person distances have similar lengths. However, in normal condition, the inter-person distances of front and rear which have angles less than° *45* are longer than the inter-person distance of left and right. In addition, these differences are greater on the corridor.

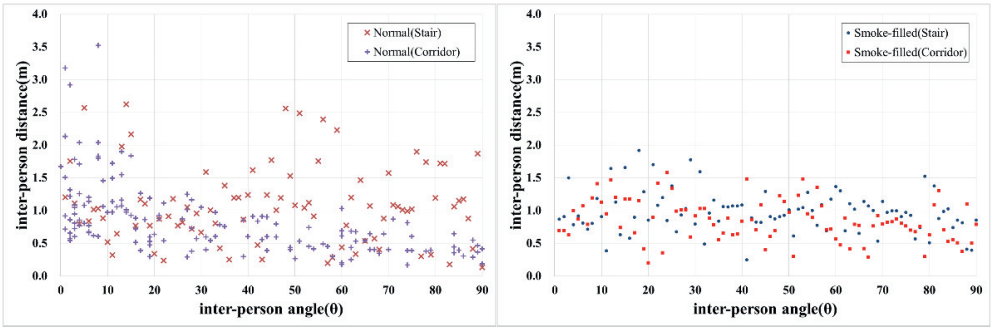

Fig. 10. Inter-person distance versus angle for (1) normal condition; (2) smoke-filled condition.

3.5. Result for cluster form estimation

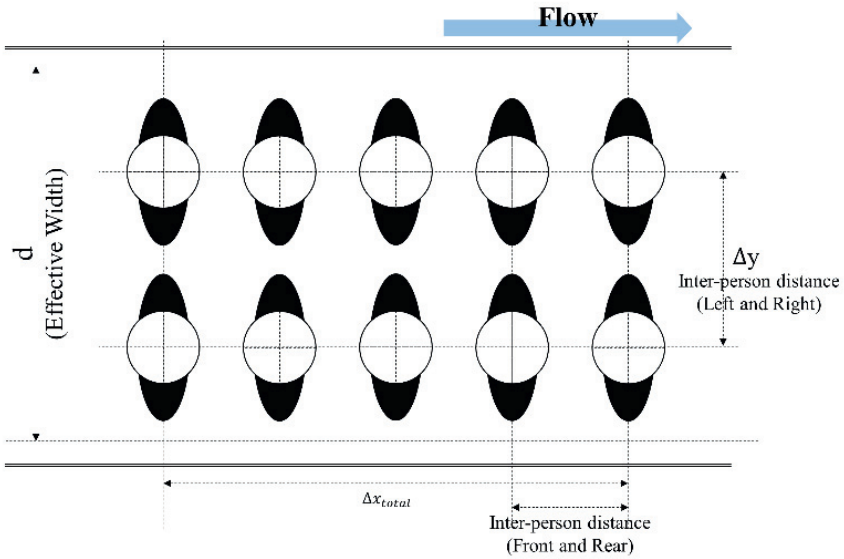

Fig. 11. Expected form of cluster.

Table 3. The densities of estimated cluster.

	Condition	Δx_{total} (m)	Δy (m)	$\theta_{f,R}$ (°)	$\theta_{l,r}$ (°)	density($1/m^2$) (Calculated value)
Stair	Normal	3.973	0.840	20	71	1.29
	Smoke-filled	3.778	0.617	20	71	1.36
Corridor	Normal	3.929	0.438	17	68	1.30
	Smoke-filled	3.241	0.389	16	75	1.57

According to the analysis of the results, we estimate the form of the cluster. We suppose that participants move only packed form which is consist of two people. Fig. 10 shows the expected form of cluster. The Δx calculated using inter-person distance and angle are *3.973m* in normal condition and *3.778m* in smoke-filled conditions on the stairs. In the corridor, the cluster lengths are *3.929m* in normal conditions and *3.241m* in smoke-filled condition. We calculate the density of the cluster according by measuring the cluster length (Δx_{total}) and the width of the path considering effective width. The calculated densities are shown in Table 3. We can confirm that density reports the most value corridors in smoke-filled condition, and decreases two areas in normal conditions.

4. Conclusion and outlook

This study analyses the distribution of inter-person distance and angle, depict inter-person distance versus angle and propose the method of cluster form. Also, we calculate cluster density using predicting density. However, the predicted cluster forms are assumed that people move only in packed form with two people in a cluster. And the forms do not apply the distribution of inter-person distance and angle. Therefore we will study to apply the distribution and staggered movement. In this way, we will be able to predict cluster formation more accurately.

Acknowledgements

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